BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D.C. 20024

69 07015

SUBJECT: Recent Studies on Materials and Structures of Radiative Heat Shields at MDAC - Case 103-8

DATE: July 2, 1969

FROM: C. C. Ong

ABSTRACT

On the basis of reentry simulation tests performed at 2400°F on specimens made of R512E coated Cb-752 Columbium alloy, engineers of MDAC provided the following opinions on reentry vehicle heat shields:

1. If a proper structural configuration is selected a minimum reusable heat shield lifetime of 20 flights is indicated. During this time frequent post flight inspection, particularly the interior of the heat shield, may not be necessary. After 20 flights excessive creep and signs of oxidation must be closely watched.

2. It is unlikely that a local oxidation due to a microscopic coating defect could result in a catastrophic structure failure during a reentry.

3. More extensive testings of structural components under different combinations of heating, pressure, and stress conditions are needed to gain more confidence in the R512E coating system.

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MEMORANDUM FOR FILE

On April 14, 1969, discussions were held with personnel of the McDonnell Douglas Astronautics Company (MDAC) at St. Louis, Missouri to review the studies being performed by the MDAC on materials and structures of radiative heat shields potentially applicable to a reusable reentry vehicle. MDAC participants were P. Bearsley, F. Bradley, D. Kummer, B. Jackson, and G. Carroll. Bellcomm participants were D. Macchia, D. E. Cassidy, and C. C. Ong.

Introduction

MDAC has several on-going research projects under Air Force contract to evaluate various materials and structural systems that can be used as heat shields. These systems include coated columbium (Cb), coated tantalum, and dispersion-strengthened nickel chromium. Although structural testings of these projects are yet to be completed, some of the preliminary test results have been found very useful in assessing the potential capability of these material systems. The coated Cb alloy has received more extensive evaluation.

Test Results of Coated Cb Structural Specimens

Single faced and stiffened panels of five different structural designs shown in Figures 1 and 2 have been tested under temperature, stress and pressure profiles similar to that given in Figure 3. These heat shield specimens were made of Cb-752 columbium alloys, sized 4" x 1" x 1/4", and coated with Sylvania R512E fused slurry silicide coating, which has a material composition of Si-20Cr-20Fe. Some important results of the oxidation tests are summarized as follows:

1. Five specimens of one of the structural designs (i.e., the flat corrugation stiffened panel) were tested under a simulated pressure/stress profile combination and a maximum temperature of 2600°F. Four of these specimens were tested through 8 to 12 cycles without coating failures. These tests were terminated because of excessive specimen deformation which was due to the high creep rate of the base metal. This deformation, if scaled up to a full size vehicle skin panel, would result in unacceptable vehicle aerodynamic characteristics.

2. Because of the excessive deformation experienced at 2600°F the peak temperature was reduced to 2400°F. Tests were conducted under conditions similar to that shown in Figure 3. It was noted that the test specimens were able to maintain structural integrity (i.e., absence of a hole through the surface) for several heating cycles after first visible oxidation of the skin. However, excessive deformation was still a problem. Therefore, creep of columbium appears to be the limiting factor rather than integrity of the surface coating.

   Figure 4 is a summary chart showing the number of simulated flights required to produce a maximum permissible deformation of 40 mils* for various heat shield base structure configurations under conditions to which they were exposed. The number of simulated flights that can produce such a deflection ranged from 13 to 60 depending on the base structural configuration. In two tests oxidation of columbium was observed before the maximum permissible deformation was reached.

3. Excluding the restrictions imposed by creep and the effects of unintentional coating damage, other test results imply that 55 heating cycles would be the minimum capability. This is established by failure of the coating** which then permits oxidation failure (i.e., hole) of the underlying columbium structure under a high stress and a heating cycle with a maximum temperature of 2400°F.

Conclusions and Recommendations

The assessments of current technology on coated Cb alloys made by the MDAC engineers are generally in agreement with those made by the Air Force personnel as reported in a previous Bellcomm memorandum.*** The opinions of the MDAC engineers are summarized as follows.

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*On a full size 10 inch square vehicle skin panel this corresponds to an indentation of 0.2 inches from the ideal aerodynamic contour.

**Figure 4 does not apply.

***Ong, C. C., "Discussions of Radiative Thermal Protection System at AFFDL and AFML, Dayton, Ohio," Bellcomm Memorandum for File, May 13, 1969.

1. Results of the MDAC studies have demonstrated the reuse capability of the Cb-752 alloy coated with R512E coating. The reusability is a function of the creep strength of the Cb alloy, the temperature, the stress, and the pressure that the structure is exposed to.

2. If a proper structural configuration is selected, it would not be necessary to inspect the heat shield frequently for oxidation of the coated internal face before the completion of 20 flights at maximum temperature of 2400°F. (Structural configuration with reentrant corners develop coating failures at these points.) Note that the estimate of 20 flights is considerably less than the implied coating life of 55 heating cycles. After 20 flights excessive creep and signs of oxidation should be closely watched.

3. Structures would continue to function for at least two missions after an oxidation coating damage occurs. Even if there is a small hole (or oxidation through the columbium) in the heat shield the hole does not enlarge at a catastrophic rate within the short period of 2 flight profiles. In other words, the likelihood of a structural failure due to oxidation of the base material during a reentry appears to be remote if the vehicle successfully passes a thorough inspection prior to flight.

4. The Sylvania R512E coating has demonstrated its protective capability. However, more testing of coated structural components under a matrix of different heating, pressure and stress combinations are needed in order to gain more confidence in this coating system.

C. C. Ong

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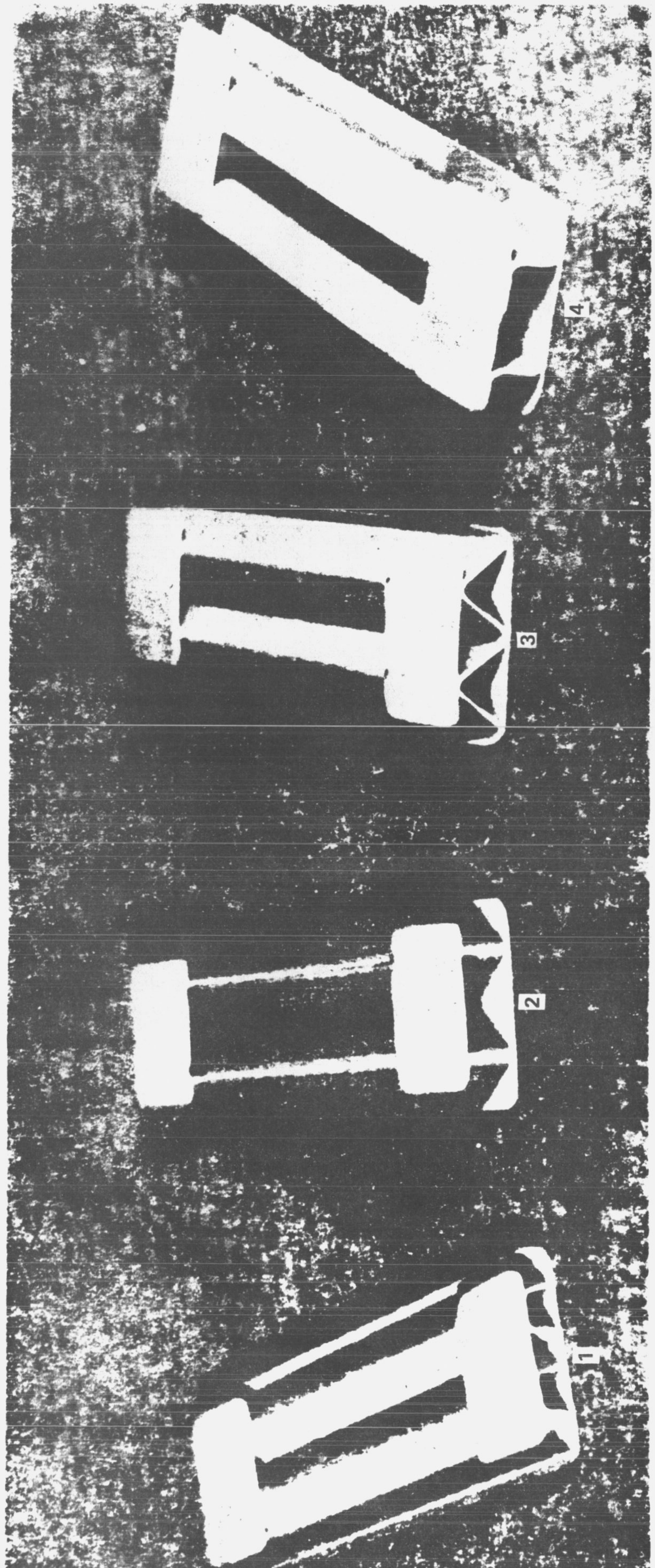
Attachments



1. SINGLE FACED FLAT CORRUGATION STIFFENED PANEL
2. SINGLE FACED RIB STIFFENED PANEL
3. SINGLE FACED VEE CORRUGATION STIFFENED PANEL
4. SINGLE FACED ZEE STIFFENED PANEL

FIGURE 1 - HEAT SHIELD TEST SPECIMENS

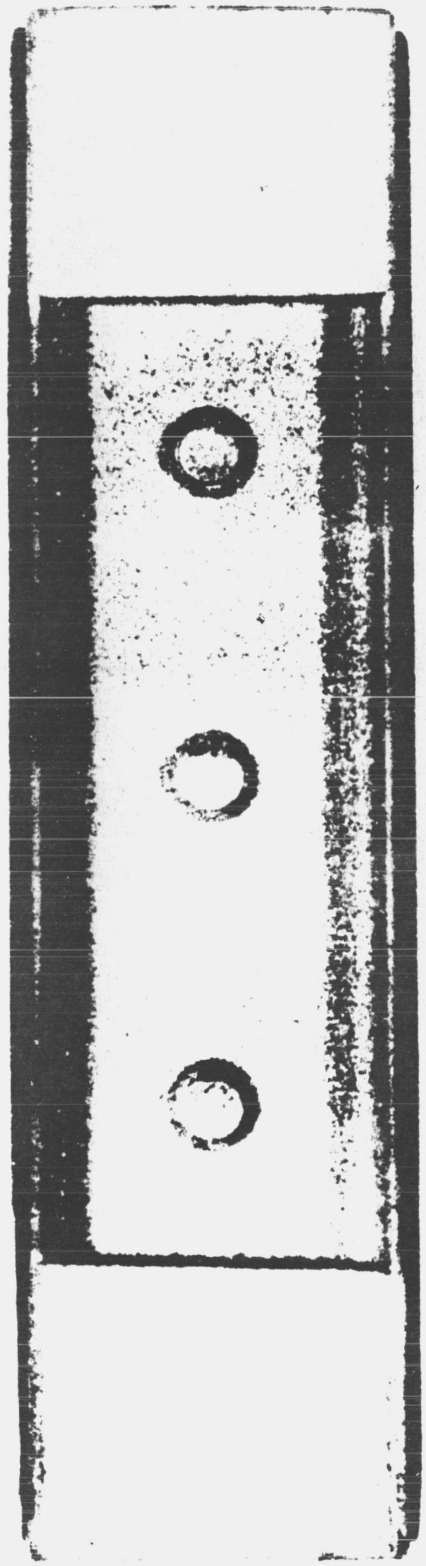


FIGURE 2- RIVETED HEAT SPECIMEN

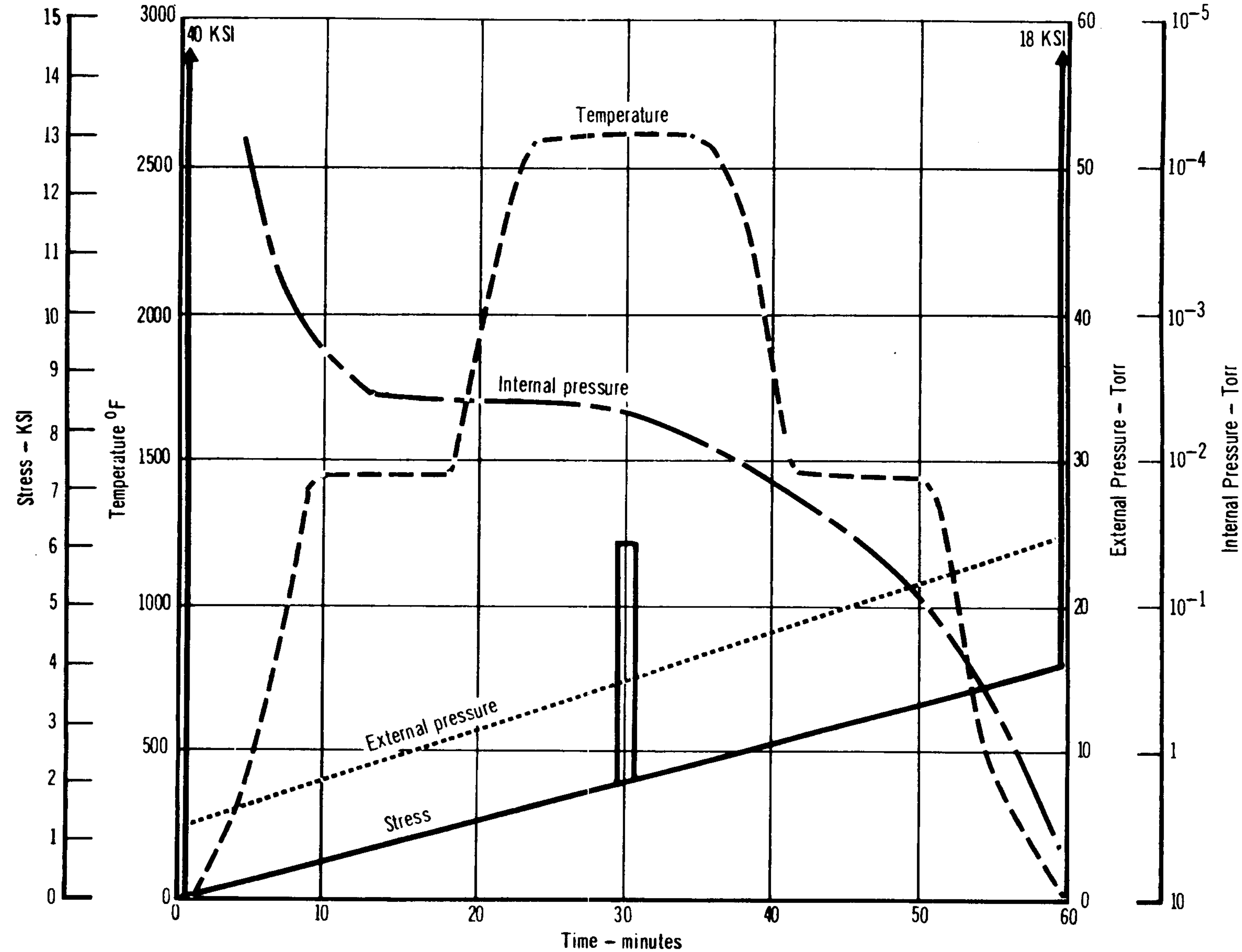
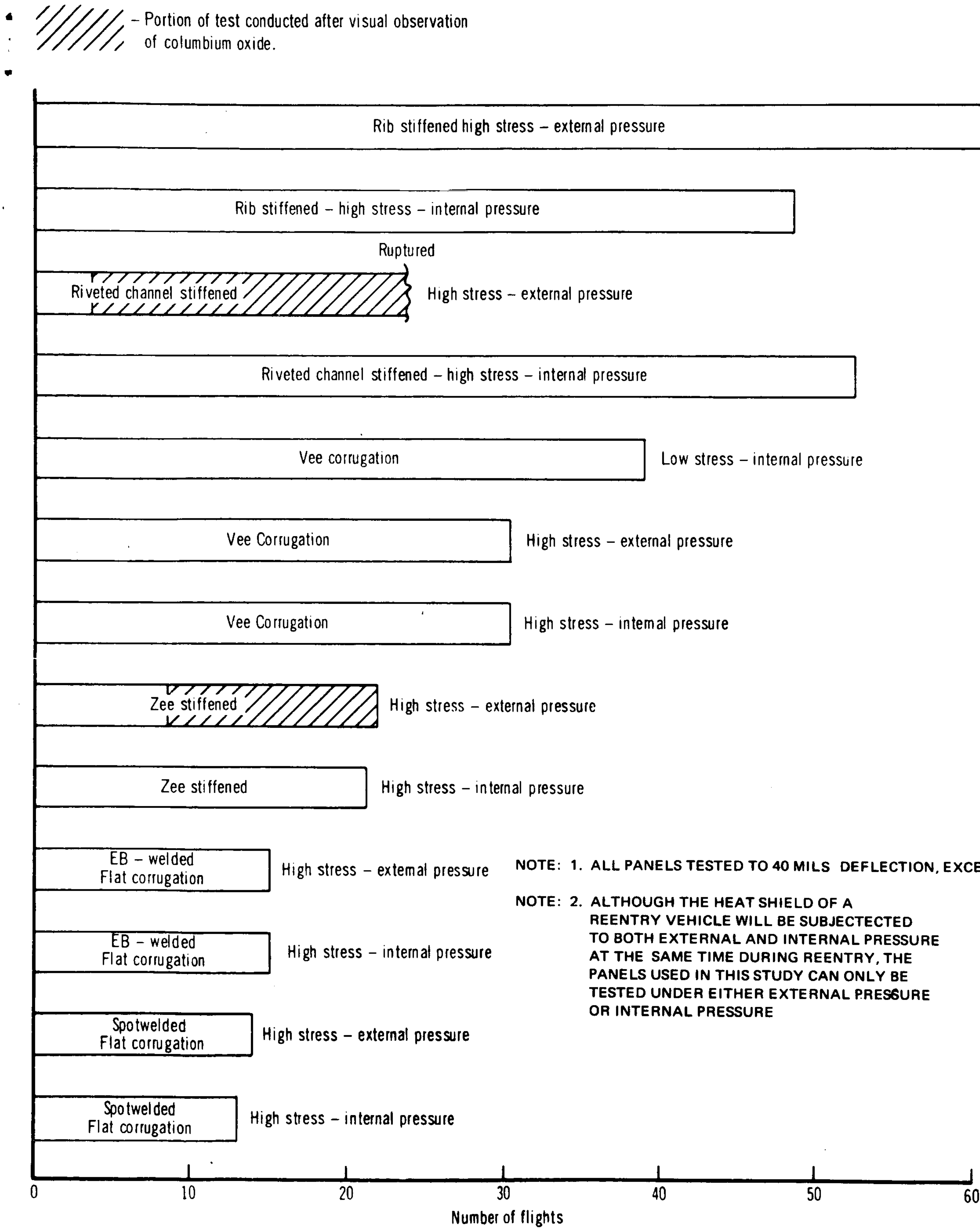


FIGURE 3 PROFILE TEST CONDITIONS OF TEMPERATURE, PRESSURE, STRESS

NOTE: THE EXTERNAL PRESSURE CURVE IS AN ASSUMED PROFILE OF THE ATMOSPHERIC PRESSURE TO WHICH THE EXTERNAL SURFACE OF THE HEAT SHIELD WOULD BE EXPOSED DURING A REENTRY, AND THE INTERNAL PRESSURE CURVE IS THE CORRESPONDING PROFILE FOR THE INTERNAL SURFACE OF THE HEAT SHIELD



NOTE: 1. ALL PANELS TESTED TO 40 MILS DEFLECTION, EXCEPT AS NOTED.

NOTE: 2. ALTHOUGH THE HEAT SHIELD OF A REENTRY VEHICLE WILL BE SUBJECTECTED TO BOTH EXTERNAL AND INTERNAL PRESSURE AT THE SAME TIME DURING REENTRY, THE PANELS USED IN THIS STUDY CAN ONLY BE TESTED UNDER EITHER EXTERNAL PRESSURE OR INTERNAL PRESSURE

FIGURE 4 HEAT SHIELD PANEL TEST RESULTS

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